

EXPERIMENTS INVESTIGATING ADVANCED MATERIALS UNDER
THERMOMECHANICAL LOADING

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ABSTRACT

Many high-temperature aircraft and rocket engine components experience large mechanical loads as well as severe thermal gradients and transients. These nonisothermal conditions are often large enough to cause inelastic (thermomechanical) deformations, which are the ultimate cause for failure in those components. A way to alleviate this problem is through improved designs based on better predictions of thermomechanical material behavior. Ongoing work at the NASA Lewis Research Center is dedicated to observing the effects of thermomechanical deformation on material behavior and evaluating and incorporating these effects into constitutive models for better prediction capabilities.

To address this concern, an experimental effort was recently initiated within the Hot Section Technology (HOST) program at Lewis. As part of this effort, two new test systems were added to the Fatigue and Structures Laboratory, which allowed thermomechanical tests to be conducted under closely controlled conditions. These systems are now being used for thermomechanical testing for the Space Station Solar Receiver program, and will be used to support development of metal matrix composites.

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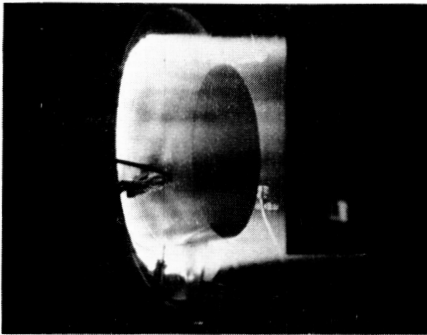
OVERVIEW

PRACTICAL OCCURRENCES OF THERMOMECHANICAL LOADING

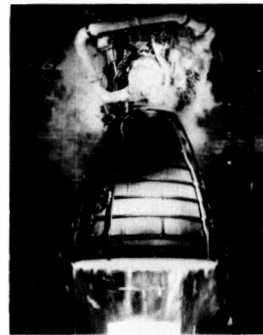
Under operating conditions, components in high-temperature applications (i.e., hot sections of aircraft and rocket engines, energy systems, etc.) are subjected to thermomechanical deformations. It is believed that such deformations are the ultimate cause of structural failure in these components. To improve life and performance, the material's thermomechanical behavior must be incorporated into the component's design. The High Temperature Fatigue and Structures Laboratory is dedicated to observing the effects of thermomechanical deformation on material behavior and integrating these effects into constitutive models to improve high-temperature component design.

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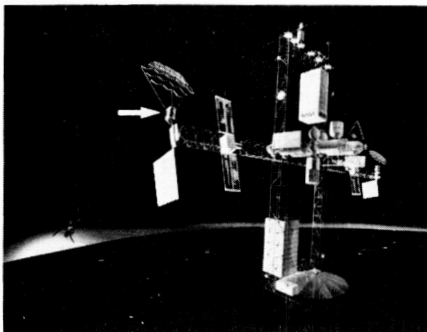
GAS TURBINE ENGINE



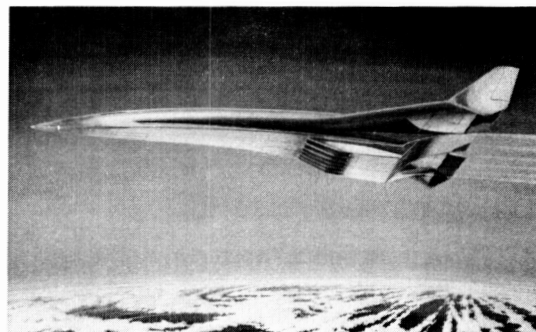
SPACE SHUTTLE MAIN ENGINE



SPACE STATION



HYPERSOONIC AIRCRAFT

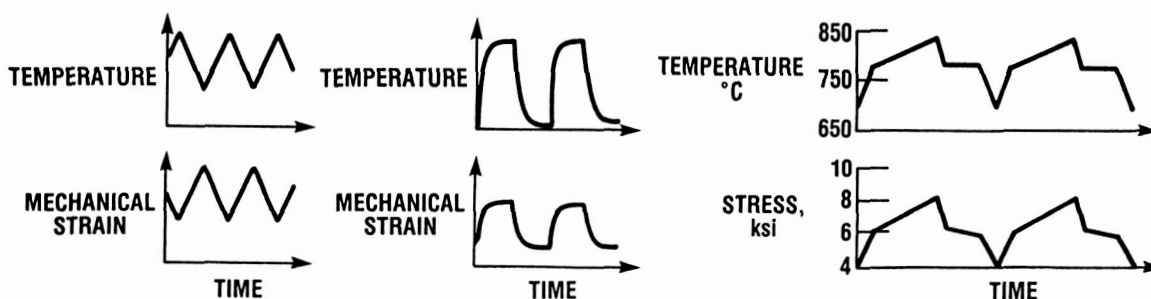
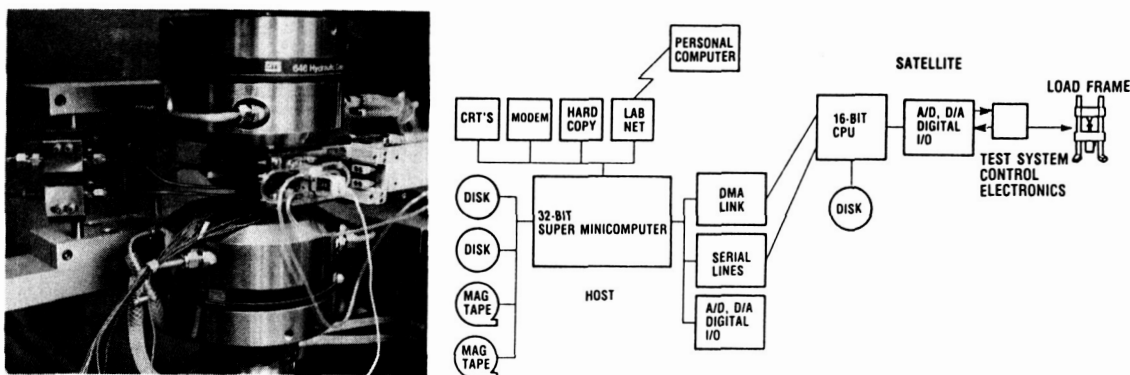


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THERMOMECHANICAL TEST CAPABILITIES

An experimental effort was initiated within the HOST Program at the NASA Lewis Research Center to enhance the thermomechanical testing capability of the High Temperature Fatigue and Structures Laboratory. As part of this effort, new test systems were obtained, and a computer testing system was developed. By utilizing this new capacity, we can subject test specimens to prototypical loading conditions and record the material response.



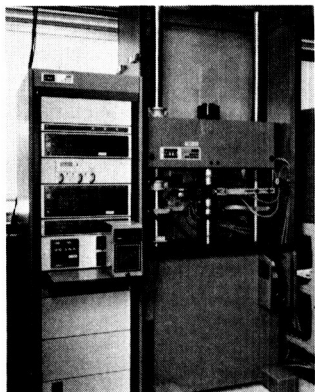
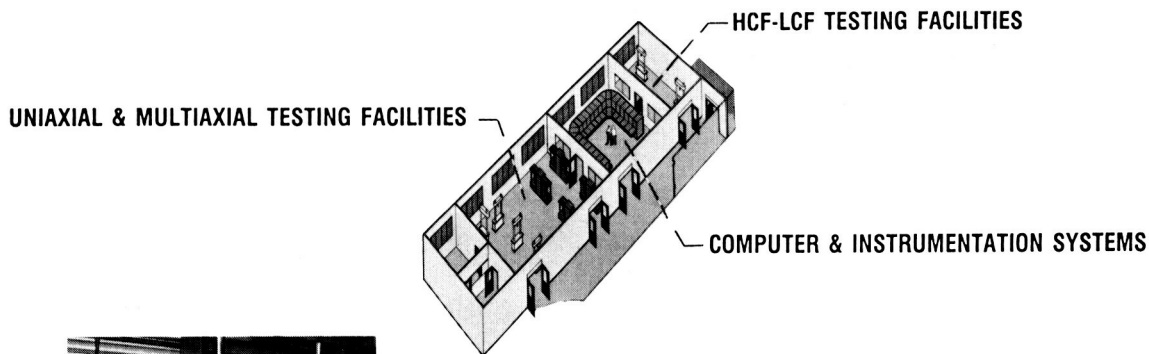
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POSTER PRESENTATION

THERMOMECHANICAL TEST SYSTEMS

The High Temperature Fatigue and Structures Laboratory at the NASA Lewis Research Center has improved its testing capability in order to investigate advanced materials under complex thermomechanical loadings. These improvements include the acquisition of new test systems, and the development of a locally distributed digital computer system for experimental control, data acquisition, and data manipulation. Two of the newly obtained test systems are dedicated to high-precision thermomechanical deformation testing. Special features of these systems include the following:

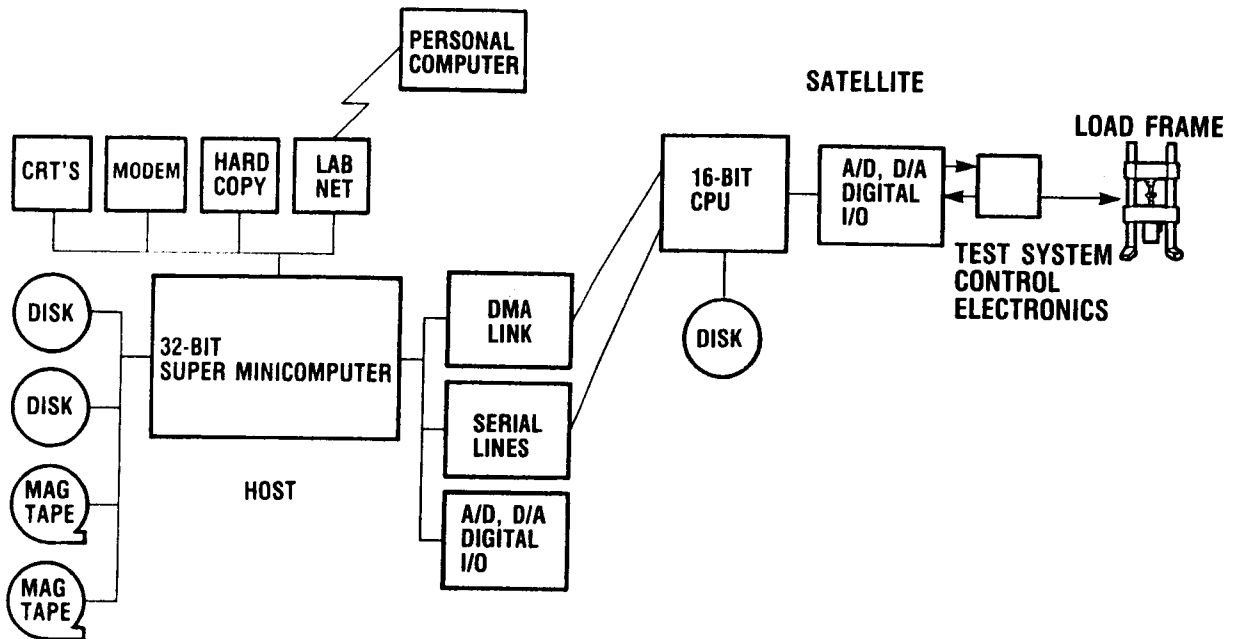
- (1) Hydraulic actuator bearings for maintaining alignment throughout the length of the stroke
- (2) Hydraulic grips for assured specimen alignment, ease of specimen installation, and specimen geometry adaptability. The grips are water cooled for protection during high-temperature testing
- (3) Dual servovalves for high system fidelity
- (4) Induction coil heating fixture for uniform temperature profile



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ARCHITECTURE OF LABORATORY'S COMPUTER TEST SYSTEM

One of the most important enhancements of the laboratory's thermomechanical capabilities is its digital computer test system. The system is composed of a host 32-bit super minicomputer, fourteen 16-bit satellite microcomputers, and four personal computers. All 19 processors are linked together by a high-speed multiprocessor communication system. The host processor is used for program development work and data storage. Each test system has a satellite processor dedicated to experimental control and data acquisition. The personal computers provide data display and plotting capabilities in addition to data analysis.

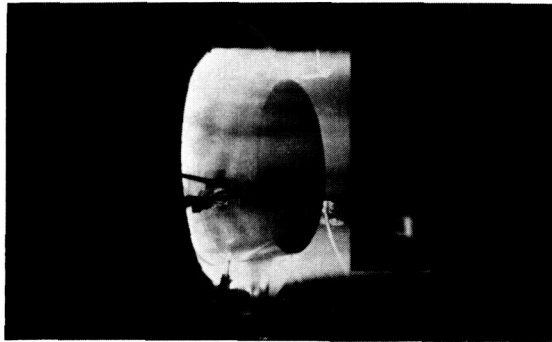


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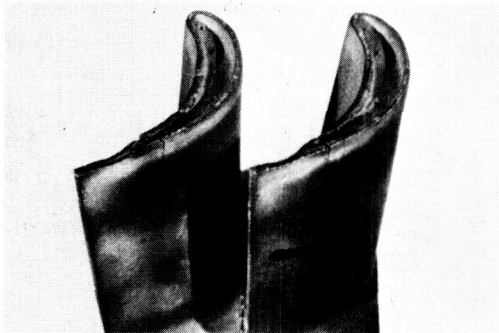
HOT SECTION GAS TURBINE PROGRAM

Recent experimental efforts towards understanding thermomechanical material behavior have been focused on the area of gas turbine engines. This effort was supported by the Hot Section Technology (HOST) program at Lewis. Utilizing the laboratory's new thermomechanical capabilities, materials for hot section components (i.e., turbine blades, combustor liners, etc.) are easily subjected to prototypical mission cycles. In this figure, we see examples of mechanical and thermal loading histories for turbine blades and combustor liners.

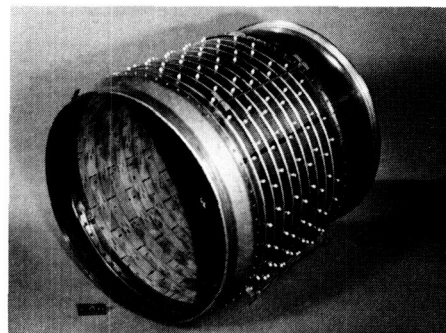
GAS TURBINE ENGINE



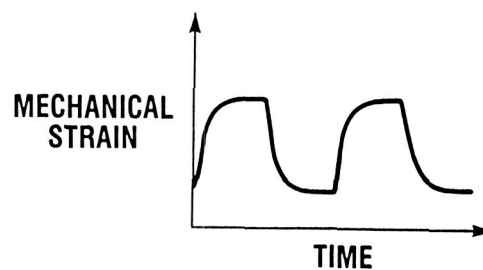
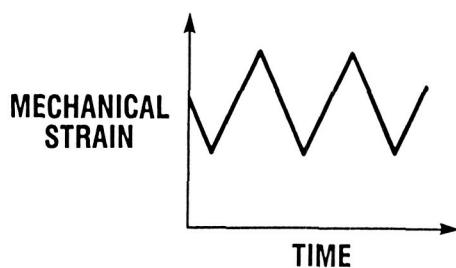
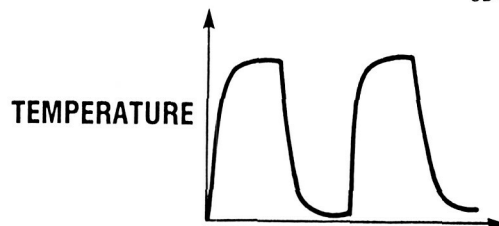
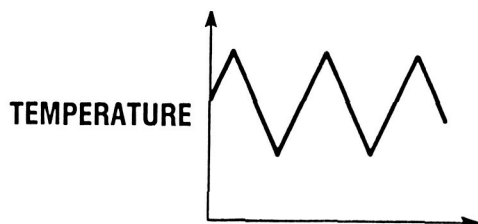
TURBINE BLADES



COMBUSTOR LINER



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SPACE STATION SOLAR RECEIVER

Initially the electrical power for the NASA space station will be provided by several sets of photovoltaic solar arrays, which will provide a 75-kW power source. Eventually, as electrical power requirements increase, the station will add two solar dynamic power systems. This upgrade will increase the electric power supply from 75 kW to 125 kW.

As the space station orbits the earth, the sun's energy is directed into the solar receiver's aperture via a set of parabolic mirrors. In the receiver the energy is used to heat 82 working fluid tubes. Once heated, this working fluid will drive a series of turbines, compressors, and generators to produce a continuous flow of electrical power. To provide a heat source during the eclipse of the station's orbit, the working fluid tubes will utilize the solar energy stored in containment canisters filled with a liquid/solid phase change material.

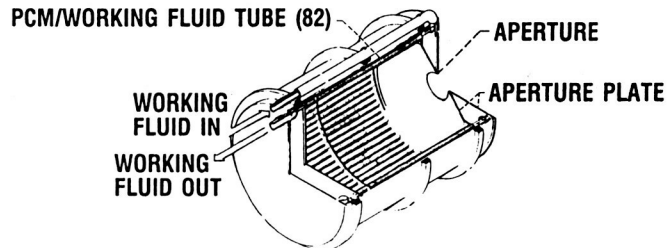
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SPACE STATION



SOLAR RECEIVER

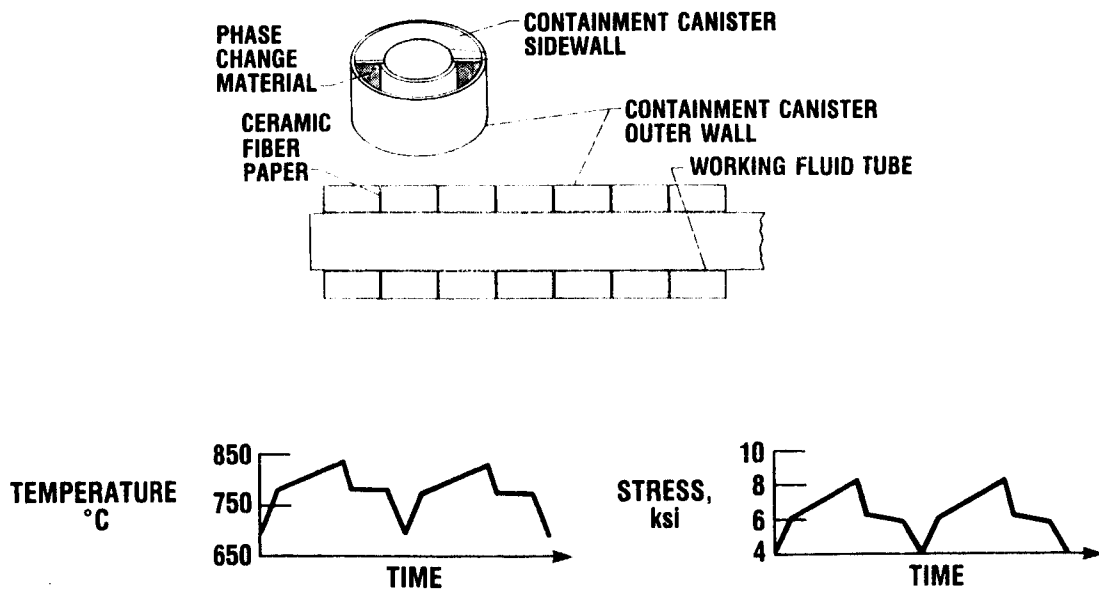
DIAMETER, 6.1 ft; LENGTH, 9.8 ft



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STRUCTURAL ANALYSIS AND EXPERIMENTAL RESPONSE OF SOLAR RECEIVER CONTAINMENT CANISTERS

Initial structural analysis of a proposed canister design determined that during its design life (30 years) the canister material (Haynes 188) will experience relatively low cyclic stresses and high service temperatures. Based upon isothermal, monotonic steady-state creep and creep rupture data, it was concluded that creep would not be a significant design factor. However, after the completion of a series of creep "threshold" and thermomechanical experiments, it was shown that there was a significant accumulation of creep strains in a matter of 90 min at stress levels as low as 4 ksi for the predicted service temperatures. Also it was observed that as the material was subjected to prototypical service cycles it exhibited creep ratcheting behavior. It is important to note that with the laboratory's new thermomechanical testing capabilities, we can easily simulate complex service loadings and measure the material response rather than having to rely on irrelevant data to calculate what might happen. Further goals of this program will aim towards the development of a constitutive model for Haynes 188 that will be incorporated into a finite element code and used to improve the overall canister design.



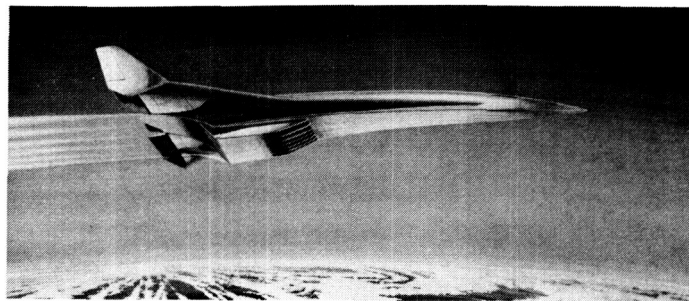
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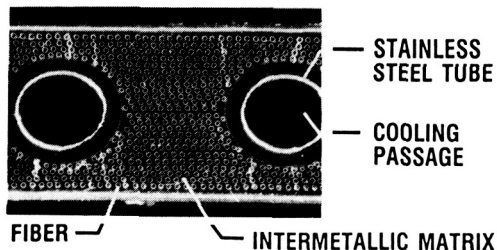
FUTURE PROGRAMS FOR THERMOMECHANICAL DEFORMATION TESTING

Design concepts for hypersonic airframes and propulsion system components dictate the use of advanced lightweight, high-strength, high-temperature materials such as metal and ceramic matrix composites. These materials will be subjected to high heat flux and thermomechanical loads induced by aerodynamic friction and complex engine operating conditions. A major obstacle (aside from material fabrication methods) for advanced composite materials to overcome is that of the mismatch of the coefficient of thermal expansion between fiber and matrix. It has been shown that this mismatch can produce large amounts of internal residual stresses within the composite system, which could lead to premature component failure. It is believed that thermomechanical testing would be an ideal method of screening candidate composite systems before the material is characterized for constitutive models. Subsequent presentations in this symposium will address the issues of thermal/structural analysis of these systems.

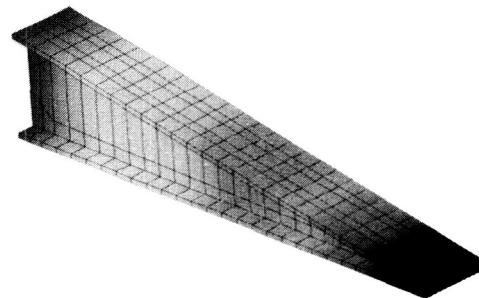
HYPERSONIC AIRCRAFT



METAL MATRIX COMPOSITE



LEADING-EDGE FINITE ELEMENT ANALYSIS



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